

Estimation of Air Toxics Emissions, Exposure, and Risk from On-Road Motor Vehicles

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Background

- Section 202(l) of 1990 CAAA:
 - Study need for controlling toxic emissions from motor vehicles and fuels (1993 MVRATS)
 - Promulgate regulations containing reasonable requirements to control toxics from motor vehicles and fuels (RFG)
- Draft Integrated Urban Air Toxics Strategy recently released
- Tier 2 emission standards recently promulgated
- Because analyses prepared for MVRATS are based on outdated models and data, there was a need for revised estimates of motor vehicle toxic emission rates, exposure, and risk

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Project Scope

Estimate on-road motor vehicle toxic emissions, exposure, and risk in ten urban areas for a variety of calendar years, control scenarios, and demo groups:

- Urban Areas:

Atlanta	Chicago
Denver	Houston
Minneapolis	New York City
Philadelphia	Phoenix
Spokane	St. Louis

- Calendar Years:

1990	1996
2007	2020

- Control Scenarios:

Baseline (NLEV and current fuel)
 Sc#1 - Base with 30 ppm S gasoline
 Sc#2 - Sc#1 with Tier 2 stds for LDVs/LDTs
 Sc#3 - Sc#2 with increased LDDTs
 Sc#4 - Tier 2 stds with a gasoline benzene cap
 Sc#5 - Tier 2 stds with a gasoline toxics std
 Sc#6 - More stringent LDV stds (beyond Tier 2)
 Sc#7 - More stringent HDGV stds
 Sc#8 - More stringent HDDV PM stds (0.01)
 Sc#9 - More stringent HDDV PM stds (0.05)

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Project Scope (Cont.)

- Seasons:

Winter	Spring
Summer	Fall
Annual Average	

- Toxics:

Benzene	Acetaldehyde
Formaldehyde	1,3-Butadiene
MTBE	Diesel PM

- Demographic Groups:

Total Population
 Outdoor Workers
 Children 0 - 17 Years of Age

- In addition to the above, a methodology was developed to generate national-level inventory and exposure estimates. Inventories were developed for each county; exposure estimates were prepared separately for urban and rural areas.

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Methodology

1. Generate toxics emission rates for all areas, years, scenarios, and seasons based on revised MOBILE inputs consistent with the Tier 2 rule
2. Generate CY1990 carbon monoxide emission rates for each area and season based on revised MOBILE inputs
3. Using 1990 CO exposure estimates ($\mu\text{g}/\text{m}^3$) from HAPEM modeling (provided for this project), develop $[\text{CO}_{\text{Exp}}(\mu\text{g}/\text{m}^3)/\text{CO}_{\text{EF}}(\text{g}/\text{mi})]_{1990}$ ratios
4. Using results from above, determine toxics exposures as follows:

$$\text{TOX}_{\text{Exp}}(\mu\text{g}/\text{m}^3) = [\text{CO}_{\text{Exp}}(\mu\text{g}/\text{m}^3)/\text{CO}_{\text{EF}}(\text{g}/\text{mi})]_{1990} \times \text{TOX}_{\text{EF}}(\text{g}/\text{mi})$$

Adjustments for atm. transformation (1,3-BD) and for VMT growth from 1990 were made

5. Exposure model includes estimates of individual cancer risk and total cancer cases:

$$\text{CAN}_{\text{Ind}} = \text{TOX}_{\text{Exp-Adj}}(\mu\text{g}/\text{m}^3) \times (\text{UR} / \text{YPL})$$

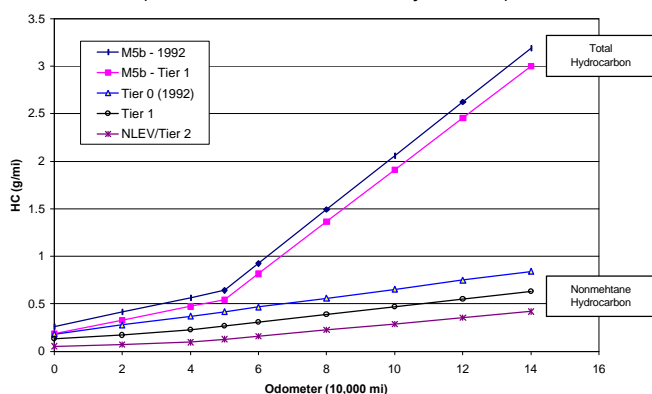
$$\text{CAN}_{\text{Pop}} = \text{CAN}_{\text{Ind}} \times \text{Population}$$

Toxics Emission Rates

TOG Methodology

- The toxics emissions estimates used TOG emission rates generated by MOBILE as a starting point
- To the extent possible, revisions planned for MOBILE6 (and used in the Tier 2 rule) were incorporated into this analysis
- Specific changes relative to MOBILE5b:
 - Revised BERs (lower DRs for 1981+ MY)
 - Incorporated off-cycle effects
 - Incorporated LEV sulfur effect
 - Revised fleet characteristics
- The above parameters were provided by EPA and were then formatted to be consistent with the modeling performed for this study

Comparison of MOBILE5b and Revised HC Base Emission Rates
Used in the Analysis of Motor Vehicle Air Toxics
(LDGV -- Conventional Fuel -- No Off-Cycle -- No I/M)



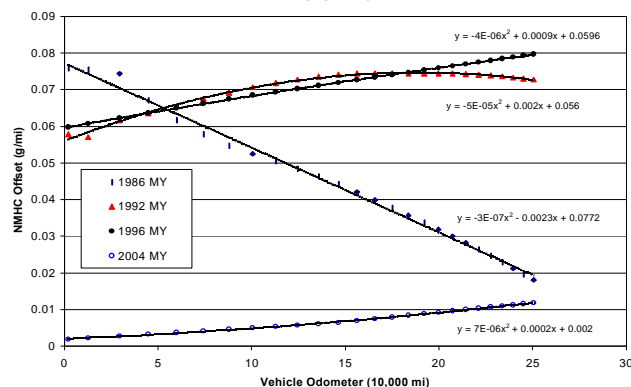
Revised Base Emission Rate Equations

Toxics Emission Rates

TOG Methodology

- Off-cycle corrections included impacts of aggressive driving behavior. An off-cycle offset as a function of vehicle mileage was developed:
- LEV sulfur effects based on correlation equations developed by EPA for Tier 2/MOBILE6
- Revised car/truck VMT splits and registration fractions based on Tier 2 modeling

NMHC Off-Cycle Offset as a Function of Mileage
LDGVs -- With I/M



Toxics Emission Rates

Toxics Methodology

- Previous estimates (MVRATS) based on applying toxics fractions to TOG emission rates
- After the release of MVRATS, the Complex model was finalized
- Current analysis was based on applying MVRATS toxics fractions for older technology and Diesels; Complex model for three-way catalyst vehicles
- Complex model provides separate estimates for normals and highs; a methodology was developed to account for this difference
- This method required development of “toxic-TOG curves” in which target fuel toxic emission rates were plotted against base fuel TOG rates

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Toxic-TOG Curve

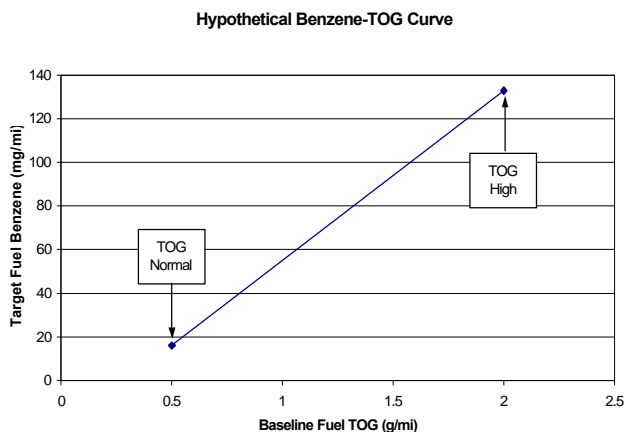
Hypothetical TOG and Benzene Emissions						
Fuel	TOG (g/mi)		Benzene Frac.		Benzene (g/mi)	
	Normal	High	Normal	High	Normal	High
Base	0.50	2.0	5%	8%	0.025	0.16
Target	0.40	1.9	4%	7%	0.016	0.133

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Toxics Emission Rates

Toxics Methodology

- Toxic-TOG Curves:
 - Complex model used for determining impact of non-sulfur fuel parameters on toxic emissions (by technology type)

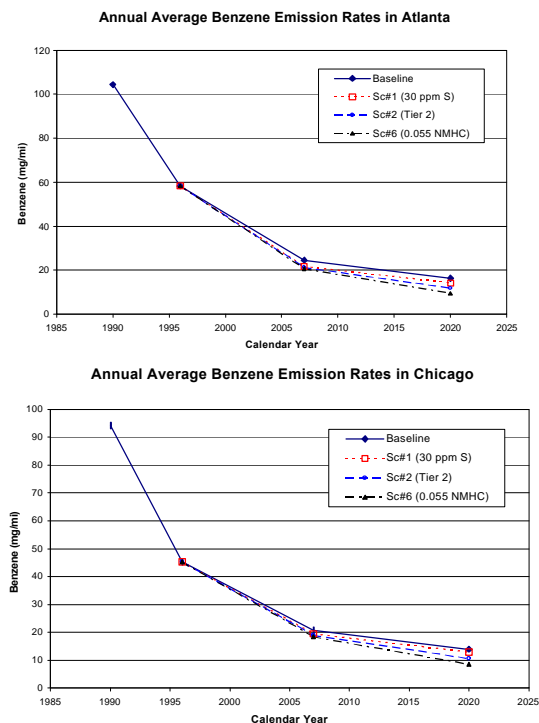


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- EPA sulfur equations used for sulfur impacts
- Tier 0 results directly from Complex model
- Tier 1 and Tier 2 normal-emitter point scaled by ratio of standards assuming same toxic fraction
- High-emitting Tier 1 and Tier 2 vehicles assumed to be the same as Tier 0 vehicles
- Off-cycle toxics fractions accounted for with adjustment factors developed from CARB UC-FTP database
- Resulting model (MOBTOX5b) incorporated revised BERs and toxics routines outlined above

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Emission Rate Results for Benzene



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Fleet-Average Benzene Emission Rates for Fuel Control Scenarios

Area	Scenario	Benzene (mg/mi)	
		2007	2020
Atlanta	Sc#2 (30 ppm S)	21.3	11.9
	Sc#4 (Bnz Cap)	22.2	12.4
	Sc#5 (25% Red.)	19.1	10.7
Cleveland	Sc#2 (30 ppm S)	24.4	13.4
	Sc#4 (Bnz Cap)	23.3	12.8
	Sc#5 (25% Red.)	21.0	11.6
Kansas City	Sc#2 (30 ppm S)	34.0	22.5
	Sc#4 (Bnz Cap)	31.7	20.8
	Sc#5 (25% Red.)	30.4	20.0
Seattle	Sc#2 (30 ppm S)	32.4	17.8
	Sc#4 (Bnz Cap)	24.8	13.7
	Sc#5 (25% Red.)	20.8	11.6

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1990 CO Emission Rates

- To the extent possible, revisions planned for MOBILE6 were incorporated into this analysis
- Specific changes relative to MOBILE5b:
 - Revised BERs (lower DRs for 1981+ MY)
 - Incorporated off-cycle effects
 - Revised oxygenated fuels benefits
- Aggressive driving effects were calculated as an offset at 75EF; A/C effects were scaled as a function of temperature and fraction equipped

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CO Exposure Estimates

- 1990 CO exposure estimates (in $\mu\text{g}/\text{m}^3$) were provided by EPA for this effort
- Estimates based on HAPTEM modeling performed by Mantech Environmental Technology
- Exposure estimates were prepared for 22 demographic groups based on time spent in each of 37 different microenvironments
- Exposure estimates were adjusted to reflect only the on-road motor vehicle contribution based on CO inventory projections
- Outdoor workers were the highest exposed demographic group, with exposure typically being 15% to 25% higher than the total population, depending on area and season

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Toxics Exposure Estimates

Modeled Urban Areas

Recall exposure calculation:

$$TOX_{Exp(\mu g/m^3)} = [CO_{Exp(\mu g/m^3)} / CO_{EF(g/mi)}]_{1990} \times TOX_{EF(g/mi)}$$

- Exposure estimates included an adjustment for atmospheric transformation only for 1,3-butadiene
- Although evidence suggests that formaldehyde and acetaldehyde should have some adjustment for transformation, the complexities in quantifying this effect prevented such an analysis for this study
- VMT adjustments were based on forecasts for each urban area provided by EPA for 1990, 1996, 2007, and 2010; estimates for 2020 were based on the annualized growth rate between 2007 and 2010
- Exposure was estimated for each urban area, calendar year, control scenario, etc. In addition, exposure attributed to individual vehicle classes was estimated

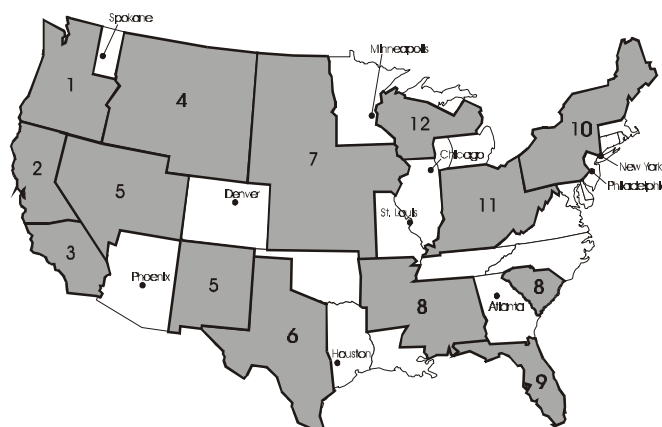
Annual Average Exposure Results for Benzene Total Population -- All On-Road Vehicles (Units: Fg/m³)

Area	Scenario	Calendar Year			
		1990	1996	2007	2020
Atlanta	Base	0.930	0.836	0.480	0.428
	Sc#1	---	---	0.424	0.374
	Sc#2	---	---	0.413	0.309
	Sc#3	---	---	0.406	0.272
	Sc#6	---	---	0.401	0.247
Chicago	Base	0.784	0.482	0.264	0.220
	Sc#1	---	---	0.248	0.204
	Sc#2	---	---	0.241	0.167
	Sc#3	---	---	0.237	0.147
	Sc#6	---	---	0.233	0.133

National-Level Emissions and Inventory Estimates

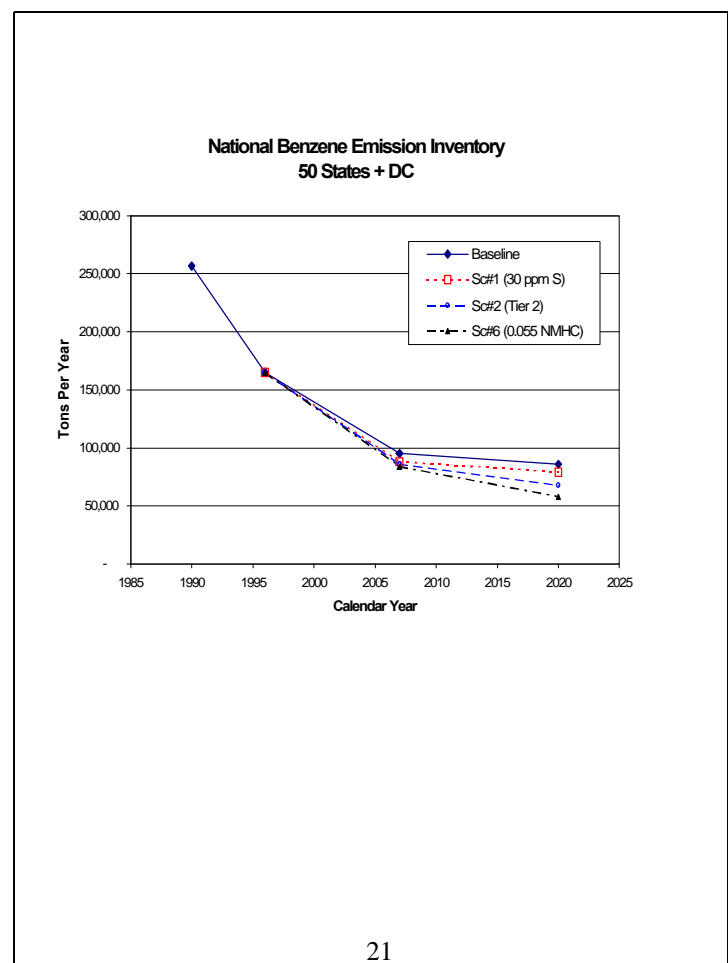
- In addition to the 10 specific urban areas modeled in this study, 16 regional areas were modeled
- The additional areas were selected to obtain a wide cross-section of fuels, I/M parameters, and temperatures
- Each county was “mapped” to one of the 26 areas for which emissions estimates were prepared
- Emission rates were combined with county-level VMT estimates to generate county-specific toxics emission inventories (in tons per year)

Nationwide Estimates – Mapped Areas



Areas Included in Toxics Emissions Modeling			
Area	Source of Fuel Data	I/M Program	Comments
Specific Urban Areas			
Chicago	AAMA	Yes	Included in original analysis
Denver	AAMA	Yes	Included in original analysis
Houston	AAMA	No/Yes	Included in original analysis
Minneapolis	AAMA	No/Yes	Included in original analysis
New York	AAMA	Yes	Included in original analysis
Philadelphia	AAMA	Yes	Included in original analysis
Phoenix	AAMA	Yes	Included in original analysis
Spokane	AAMA	Yes	Included in original analysis
St. Louis	AAMA	Yes	Included in original analysis
Atlanta	AAMA	Yes	Specifically requested for this study
Additional Geographic Regions			
Western Washington/Oregon	NIPER Dist. 13	Yes	Used to model Seattle, Portland, etc.
Northern California	AAMA - SF	Yes	San Francisco AAMA data to be used
Southern California	NIPER Dist. 15	Yes	Used for Southern California
Idaho/Montana/Wyoming	NIPER Dist. 9	No	NW Idaho mapped to Spokane
Utah/New Mexico/Nevada	NIPER Dist. 10	Yes	Colorado mapped to Denver
ND/SD/NB/IA/KS/Western MO	NIPER Dist. 7	No	Eastern MO mapped to St. Louis
Southeast -- AR/MS/AL/SC/Northern LA/etc.	NIPER Dist. 3	No	Southern LA (New Orleans) mapped to Atlanta
Florida	NIPER Dist. 4	Yes	Use regional fuel data rather than AAMA - Miami
Northeast states -- non-I/M and non-RFG	NIPER Dist. 1	No	Use for Northeast areas without I/M and RFG
Northeast states -- non-I/M and with RFG	NIPER Dist. 2	No	Use for Northeast areas without I/M but with RFG
Northeast states -- with I/M and non-RFG	NIPER Dist. 1	Yes	Use for Northeast areas with I/M but w/o RFG
Ohio Valley -- non-I/M and non-RFG	NIPER Dist. 6	No	Use for IN/OH/WV/KY areas without I/M and RFG
Ohio Valley -- with I/M and non-RFG	NIPER Dist. 6	Yes	Use for IN/OH/WV/KY areas with I/M but w/o RFG
Ohio Valley -- with I/M and with RFG	NIPER Dist. 6	Yes	KY areas with RFG and I/M; Chicago used for NW Indiana
West Texas	NIPER Dist. 11	No	Use for West Texas and Oklahoma
Northern MI/WI	NIPER Dist. 5	No	Milwaukee mapped to Chicago; Detroit mapped to Ohio Valley

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Toxics Exposure Estimates National Analysis

- Exposure estimates were calculated separately for urban and rural areas
- 1990 Urban CO Exposure:
 - Population-weighted annual average ambient CO for modeled areas = 1.32 ppm
 - Population-weighted annual average ambient CO for U.S. urban areas = 1.22 ppm
 - The population-weighted CO exposure for the modeled areas was then scaled by the ratio 1.22/1.32 (by season and demo group)
- 1990 Rural CO Exposure:
 - No rural areas were modeled in this effort
 - In the 1993 MVRATS, average annual urban CO exposure was 842 $\mu\text{g}/\text{m}^3$; rural was 470 $\mu\text{g}/\text{m}^3$

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- Average urban exposures were scaled by the ratio 470/842 to generate rural estimates

Toxics Exposure Estimates National Analysis (Cont.)

- CO and Toxics Emission Rates:
 - Each county of the U.S. was mapped to one of the 10 modeled urban areas or 16 regional areas
 - Urban and rural emissions determined by weighting emission rates by VMT
 - Urban/rural designations based on 112(k) report
- Population and VMT Forecasts
 - 1990 Census data forecast to the future based on the population growth in the mapped area
 - VMT forecasts were based on applying the VMT/population ratio to the population forecasts

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- From this point, the same approach as outlined above was used to generate exposure estimates for average urban and average rural areas

National-Level Annual Average Exposure Results for Benzene Total Population -- All On-Road Vehicles (Units: Eg/m³)					
Area	Scenario	Calendar Year			
		1990	1996	2007	2020
Urban	Base	1.153	0.735	0.420	0.375
	Sc#1	---	---	0.390	0.346
	Sc#2	---	---	0.381	0.293
	Sc#3	---	---	0.373	0.256
	Sc#6	---	---	0.371	0.250
Rural	Base	0.648	0.433	0.261	0.243
	Sc#1	---	---	0.239	0.222
	Sc#2	---	---	0.233	0.193
	Sc#3	---	---	0.228	0.167
	Sc#6	---	---	0.228	0.170
50-State	Base	1.067	0.683	0.393	0.353
	Sc#1	---	---	0.364	0.326
	Sc#2	---	---	0.356	0.277
	Sc#3	---	---	0.348	0.241
	Sc#6	---	---	0.347	0.236

Risk Assessment

- Using the on-road motor vehicle toxics exposure estimates described above, individual cancer risk and total cancer cases were calculated:

$$CAN_{Ind} = TOX_{Exp-Adj(\mu g/m^3)} \times (UR / YPL)$$

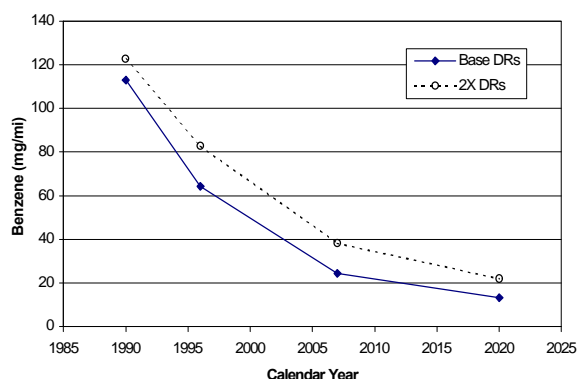
$$CAN_{Pop} = CAN_{Ind} \times Population$$

- A range of unit risk in $(\mu g/m^3)^{-1}$ is input to the model (low-range and high-range) as is years per lifetime (typically 70)
- Individual risk and cancer cases are generated for the modeled urban areas and for an “average” urban and “average” rural area (for national estimates)

- Population forecasts based on above estimates used to generate VMT/population ratios

Sensitivity Analysis Double Deterioration Rates

Impact of Doubling LDV Deterioration Rates
On Fleet-Average Benzene Emissions
(Ohio Valley – I/M)



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Sensitivity Analysis Min/Max Fuel Parameters

Results of Sensitivity Case #2:
Comparison of CY1996 Results Using
Minimum/Maximum Fuel Parameters in Four Urban Areas
(LDGV Summer Emissions)

Area	Parameter	Min/ Max	Parameter Value	Benzene (mg/mi)	Form. (mg/mi)
Cleveland	Sulfur	Min	80 ppm	48.4	11.2
		Max	820 ppm	60.6	11.7
Minneap.	Aromatic	Min	5.2 vol%	17.2	11.7
		Max	35.1 vol%	52.6	11.1
Philly	Olefins	Min	7.0 vol%	28.9	13.5
		Max	22.8 vol%	29.2	13.2
Seattle	Benzene	Min	1.4 vol%	55.0	11.5
		Max	4.2 vol%	147.3	9.0

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Summary and Conclusions

- Revised toxics model (MOBTOX5b) reflects an improvement over previous estimates, incorporating updated BERs consistent with the Tier 2 rule and toxics fractions based on the Complex Model.
- For the national-level emissions analysis, each county was mapped to one of 26 modeled areas. Local-level estimates could be improved by using data on fuel properties that are specific to the area being modeled.
- Overall, significant reductions in motor vehicle related air toxics are expected between 1990 and 2020 (i.e., from 75% to 90%).

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